6.9 MONITORING OCEAN-ATMOSPHERE EXCHANGES FROM SPACE

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1. INTRODUCTION

The ocean and the atmosphere are coupled by the fluxes of momentum, heat, and water, but in situ measurements of these fluxes are sparse and uneven. Global fields of these fluxes can be derived from satellite data or obtained from operational numerical weather prediction (NWP) models. The NWP models provide quality control and dynamic interpolation of sparse and uneven data. However, dynamic interpolation is only as good as the model physics and parameterization scheme; those in the atmospheric boundary layer are known to be deficient. Over most of the ocean, there may not be sufficient data for any useful interpolation. Operational NWP models change frequently; the results are inconsistent of climatic studies. Reanalysis to produce long period of consistent data have only been started recently. Adequate observations at temporal and spatial scales significant to global change research can only be achieved from the vantage point of space. Spaceborne sensors provide repeated global observations of some parameters from which these fluxes can be derived. The status and shortfalls of spacebased estimation of the fluxes will be summarized and assessed in this report. Satellite data can be assimilated into numerical model to simulate surface fluxes, but the progress in developing assimilation technique of unconventional satellite data has been slow.

2. MOMENTUM FLUX

The flux of momentum and kinetic energy are resulted from wind shear. There are three sets of spacebased global wind field available now and in the near future. The Special Sensor Microwave /Imager (SSM/I) on the operational spacecraft of the Defense Meteorological Space Program has provided continuous wind speed measurements over global ocean since July 1987 [Wentz, 1996]. It has a wide scan and, therefore, good coverage, but lacks directional information. The wind speed from SSMI has been combined with other available wind data through a variation method to produce wind vector fields at 6 hourly interval and 2° by 2.5° resolution. These wind fields were found to generate more realistic anomalous ocean cooling in an ocean general circulation model [Liu, et al., 1996]. SSM/I is an operational sensor and data availability will be continued well into the next century. The production of wind vector, however, is a research effort.

There are scatterometers on board European Remote Sensing Satellites (ERS) which were specifically designed to measure surface wind vector [Attema, 1991]. ERS-1 was launched in 1991 with a C-band scatterometer and it was replaced by a duplicate on ERS-2 in 1996. Unfortunately the ERS scatterometers scan a narrow 475 km swath only on one side of the spacecraft and leaves large data gaps between passes; the coverage is less than half of SSMI. ERS winds from January 1992 have been available but the distribution is restricted. The next European scatterometer will also be C band scatterometer, but scanning on both sides, on the Meteorology Operational Platform (METOP) to be launched in 2003.

The NASA scatterometer (NSCAT) was launched in August 1996 on the Japanese spacecraft ADEOS-1. The six fan-beam antennas scan two 600 km swaths on both sides and will have more than twice the coverage of ERS scatterometers. It covers over 87% of the ocean in one days, and 97% in two days, under both clear and cloudy conditions. NSCAT measures at Ku-band which has been studied more vigorously than

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C-band. The backscatter measured by NSCAT has 25 km resolution which is an improvement over the 50 km resolution of the ERS scatterometers. Liu et al. [1998] demonstrated that NSCAT winds have more structure than winds field provided by operational numerical weather prediction. NSCAT is supposed to be followed by SeaWinds, on ADEOS-2 to be launched in 1999. Unfortunately, ADEOS-1 suffered terminal failure on June 30, 1997 and NSCAT ceased functioning. NASA has approved a new start for the Quick Scatterometer (Quikscat) mission to reduce the data gap between NSCAT and SeaWinds. It is scheduled to be launched in December 1998, and the launch of SeaWinds will be delayed to 2000. Quikscat and SeaWinds will use pencil-bean-antennas in a conical-scan design which is more compact than the fixed fan-beam design of NSCAT. They will measure across a continuous 1800 km swath, providing 25 km resolution ocean surface wind velocity over 92% of the ocean every day. Spacebased observations of wind vector will be continued on the National Polar-orbiting Operational Satellite System (NPOESS) in the next century. Summaries of scatterometry and examples of applications of European and U.S. sca tterometers are given by Liu and Tang [1997].

3. HEAT FLUX

Air-sea heat flux can be divided into four components; sensible heat resulted from thermal gradient, latent heat (LF) carried by evaporation, shortwave radiation (SR) from the sun and longwave radiation from the atmosphere and the ocean. Shortwave radiation and latent heat flux are the larger variable components over most of the tropical and temperate oceans.

Global SR has been computed from the Earth Radiation Budget Experiment (ERBE) data from 1985 to 1989 [Li and Leighton, 1993]. The variability of SR is largely controlled by the variability of clouds and most of the computations of SR make use of the high resolution and high sampling of data from geostationary satellites. The International Satellite Cloud Climatology Project (ISCCP) has provided calibrated and standardized cloud data from 4 geostationary satellites operated by the U.S., the Japanese, and the European space agencies. A number of methods [e.g., Gautier, et al., 1980; Bishop and Rossow, 1991; Pinker and Laszlo, 1992] have been used to compute SR at daily and 2° by 2.5° resolution, including the operational effort by the Surface Radiation Budget Program at Langley Research Center. The availability of ISCCP data is expected well into the future. The launching of sensors for the Earth Observation Program, including CERES (Clouds and Earth Radiant Energy System) will advance the derivation of SR. The computation of LF requires sea surface temperature (SST), wind speed (u), and humidity at a level within the surface layer (q). Over ocean, u and SST have been directly retrieved from satellite data, but not q. A method of estimating q and LF from the ocean, using satellite data was proposed [Liu and Niiler, 1984] which is based on an empirical relation between the integrated water vapor (measured by spaceborne microwave radiometer) and q (required to compute evaporation) in the monthly time scale [Liu, 1986]. The physical rationale is that the vertical distribution of water vapor through the whole depth of atmosphere is coherent for period longer than a week [Liu et al., 1991]. The relation does not work well at synoptic and shorter time scales and also fails in some regions during summer [Liu et al., 1992]. The relation have also been scrutinized in a number of studies [e.g., Hsu and Blanchard, 1989; Esbensen, et al., 1993; Jourdan and Gautier, 1994]. Modification of this method by including additional geophysical parameters or EOF functions as estimators have been proposed [Wagner, et al.,1990; Cresswell, et al., 1991; Miller and Katsaros, 1991; Chou et al.,1995]. Direct retrieval of q and LF from the observed brightness temperatures has also been demonstrated [e.g., Liu 1990; Schulz et al., 1993]. Future advanced microwave humidity sounders may improve the accuracy and temporal resolution of evaporation estimation.

It is much more difficult to estimate sensible heat flux and longwave radiation from satellite data. The magnitude and variability of sensible heat are relatively small over much of the ocean and near surface air temperature is difficult to retrieve with sufficient accuracy. It can be derived from LF if the relative humidity or the Bowen Ratio is known, but the accuracy is uncertain [Liu and Niiler, 1990]. Longwave radiation is strongly affected by atmospheric properties below cloud base which are hidden from spaceborne sensors. Methods that combined cloud information with atmospheric soundings and numerical models have been attempted [e.g., Frouin et al., 1988; Gupta et al., 1992]. Improved atmospheric temperature sounders such as Atmospheric Infrared Sounder (AIRS), scheduled to be launched early next decade may advance the estimation of these fluxes.

4. WATER FLUX

Hydrologic forcing is the difference between precipitation and evaporation. The estimation of evaporation is the same as the estimation of latent heat flux discussed above. Attempts have also been made to estimate precipitation from spaceborne sensors at visible, infrared, and microwave wavelengths [Arkin and Ardanuy, 1989; Wilheit et al., 1991]. Passive microwave sensors have the advantage of more directly related to rain but are limited by the insufficient sampling of the diurnal cycle by the polar orbiters. Data production and validation have been undertaken by the Global Precipitation Climatology Project (GPCP) and data at 2.5° and monthly resolutions from 1986 to 1994 are available. Precipitation for a very long period of time has also been derived from the operational Microwave Sounding Unit [Spencer, 1993]. Improvement in rain measurement is expected with the launching the Tropical Rain Measuring Mission [TRMM] in 1997.

5. ASSESSMENT

At present, the method to estimate momentum flux over global ocean using spacebased data is reasonably validated. We could discern the annual variations over a large part of the global ocean and El Niño anomalies over the tropical ocean of the two major components of heat flux. However, we do not have the absolute accuracy of the net heat flux to compute the average meridional ocean heat transport from spacebased heat flux estimates. The validation of spacebased estimation of precipitation has been hampered by the lack accurate standard.

Surface wind measurement is sustainable if the series of planned scatterometers are approved, but scrutiny is needed to assure data quality in the transitional plan from research to operational sensors. While present methods of estimating heat and water fluxes rely on operational sensors which are sustainable, the estimation of the fluxes from the satellite data are largely research efforts that need to be supported, before more stable and operational methods emerge. Improvement in coverage and resolution should be pursued to enable the studies of storms and coastal oceans.

The surface signatures of ocean's response to these surface forcing observed by spaceborne sensors are sea level deviation, sea surface temperature, and surface salinity. An integrated approach to study these forcing and response should be pursued and there is potential to develop integrated sensors for monitoring these parameters. The limited life-span of a single sensor requires continuous sensor deployment to study interannual to decadal changes. Spacebased estimation of these fluxes, at present, required synergistic combination of multiple sensors from different flight projects. Because spaceborne sensors are expensive and require long lead time to develop, continuous vigilance from the scientific community to advocate and coordinate is necessary to shepherd these space programs to fruition. Coordination in sensor deployment and data processing is needed to have coincident or continuous data.

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